Use of a Circulation Model to Enhance Predictability of Bioluminescence in the Coastal Ocean

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LONG-TERM GOALS

The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments.

OBJECTIVES

Our objective is to develop the technology and methodology to optimize limited spatial and temporal bioluminescence (BL) sampling for maximum impact on short-term (2-3 days) BL forecasts.

APPROACH

The BL forecasts are conducted by assimilating limited BL observations into an advective-diffusive tracer model with the velocities and diffusivities from a nested, data-assimilating coastal circulation model of the Monterey Bay area (named the ICON model due to NOPP sponsored project "Innovative Coastal-Ocean Observing Network" (ICON)) and with a finer-resolution sub model of the ICON

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14. ABSTRACT
The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments.

15. SUBJECT TERMS

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model (frsICON) around the upwelling front at the north of the Monterey Bay (Shulman et al., 2002, Shulman et al., 2003). Data sets used in this study include ongoing observational efforts by Drs. Haddock (MBARI) and Moline (CalPoly), as well as observational and modeling efforts of the ONR "Autonomous Ocean Sampling Network" (AOSN-II) experiments. During each of the three oceanographic seasons typical in this area, BL is measured along radial sections covering the Bay. These observations are being made through two full sets of seasonal cycles. This coincident sampling of the BL and physical variables will allow crucial testing of our techniques, which would not be possible without data sets collected on comparable spatial and temporal scales. A significant enhancement to the hydrodynamic model is the inclusion of tidal forcing.

Research is being performed in collaboration with an interdisciplinary research team involved in the AOSN II experiment in the Monterey Bay (researchers are from MBARI, WHOI, Harvard, Princeton, Caltech, NPS, CalPoly, JPL and NRL Monterey). Research on adjoint calculations and sensitivity studies is being performed in collaboration with Dr. Nechaev (USM).

WORK COMPLETED

The Monterey Bay area model (ICON) was run over the time frame of the MBARI Spoke cruise in August of 2002. Preliminary particle tracking and tracer simulations experiments were conducted by using BL data from Steve Haddock's Spoke cruise and Mark Moline's REMUS transects. The results are being compared to simulations conducted during the MUSE experiment of 2000. Beta version of the adjoint code for the tracer routine of the ICON Monterey Bay area model was developed. Preliminary sensitivity simulations with adjoint code were conducted.

We have been participating in the development of the objectives, as well as in the design and planning, of the ONR AOSN-II adaptive sampling experiment in the Monterey Bay. Historical outputs from ICON model predictions together with atmospheric forcing were provided to the AOSN community, and have been used for calibration and tune ups of HOPS and ROMS models, as well as skill assessments. We participated in on-site discussions during the intensive August 2003 experiment, to help assess local oceanographic conditions and provide guidance for experiment direction. We are also working with others to develop a high spatial resolution regional temperature and salinity climatology for use by all the modelers working in this area. We have compiled, reformatted, documented, and made available almost 3000 CTD profiles collected by NPS PIs over the past 10 years.

Initial prototypes of simulation experiments in optimal control and adaptive sampling with groups of gliders are being tested, and preliminary estimations of Lagrangian Coherent Structures (LCS) in the Monterey Bay were computed (Fiorelli et al., 2003, N. Leonard, AOSN Executive Team meeting presentation, 05/14/2003).

Historical sea level, bottom pressure, and current records have been collected, and tidal analyses performed on them. Tidal forcing was implemented in the ICON model. In order to introduce tidal forcing into the model, tidal amplitudes and phases from Oregon State Tidal Solution for US West Coast were used in the ICON open boundary conditions specification. An important effort of testing of the tidal-period forcing implementation within the ICON circulation model is under way.

RESULTS

In (Shulman et al., 2003), bioluminescence potential predictability experiments were conducted by using tracer dynamics. Two cross-shore surveys of BL conducted during the MUSE (August of 2000) experiment were used in this study (Fig.1, left panel). The physical conditions in the Bay represented a wind relaxation event, with strong offshore currents directed to the south-southeast, and at the same time a northward flowing coastal jet developed south of Monterey Bay at Point Pinos (Fig. 1, left panel).

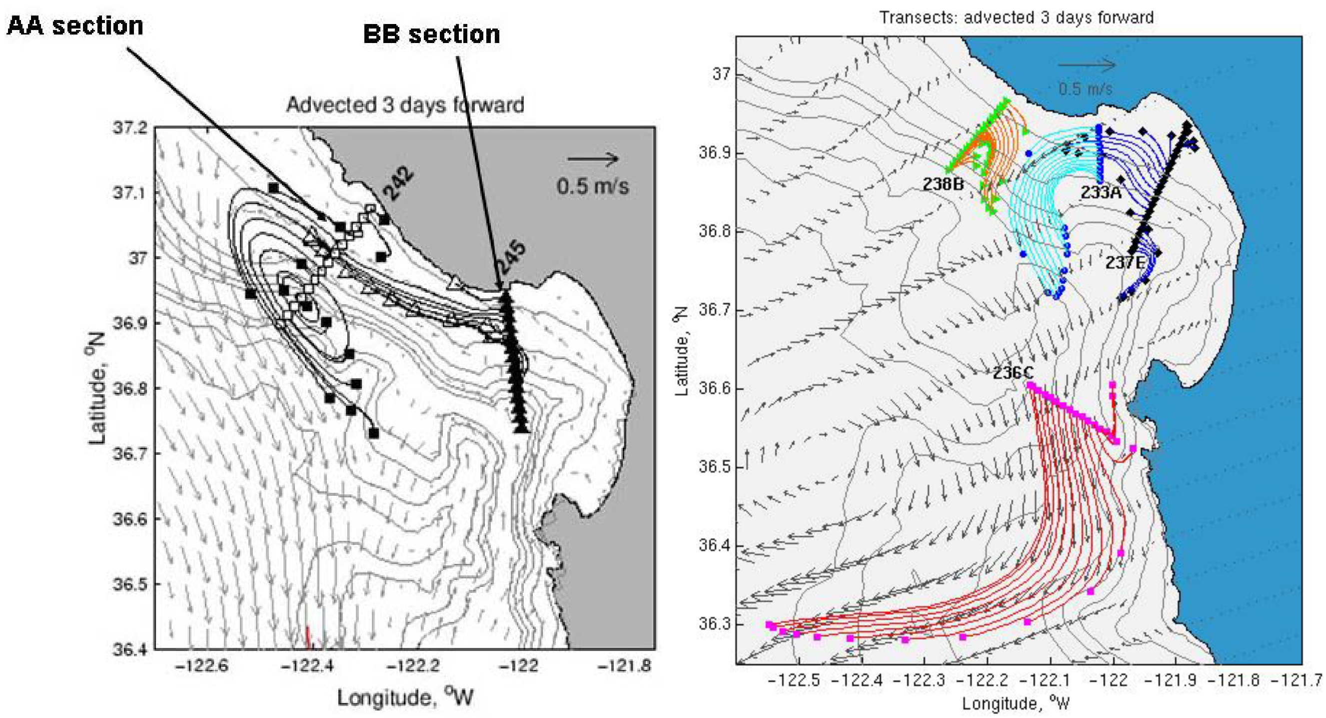

Figure 1. Three days of forward advection of particles. Left panel shows advection of particles placed along two BL surveys conducted during MUSE (August of 2000) experiment (AA – section to the north of the Bay, BB – section inside the Bay). Right panel shows advection of particles placed along four BL sections of Spoke cruise in August of 2002.

Due to development of this northward jet during the wind relaxation event, numerical experiments showed that sampling of BL inside the Bay (section BB) plays important role in BL predictability at section AA outside the Bay (Fig. 2). The assimilation of only the inside-the-Bay (BB survey) data into the tracer model gave a good reconstruction of the observed location of the BL maximum (Fig. 2a and Fig. 2c) at the outside-the-Bay (section AA). The BL distribution at the AA location after three days of prognostic calculations (on 245 day) is shown on Fig. 2d. After those three days of prognostic calculations, the BL maximum moved closer to shore and became shallower. Also, the intensity of the BL maximum was stronger after three days. This corresponds to the temporal and spatial tendencies in the observed BL maximum distributions during days 242 and 245, although they were observed at different times and locations along the coast (Fig. 2). We found that during the wind relaxation event, the locations of the observed and model-predicted BL maxima coincide with the location of the high horizontal shear frontal area where the flow reverses direction.

In contrast to the wind relaxation event during August of 2000, the first Spoke cruise in August of 2002 took place during upwelling-favorable conditions. The results of particle tracking experiments are presented in Fig. 1, right panel. The current structure is that of equatorward flow across the mouth of the Bay, and a cyclonic eddy inside the Bay.

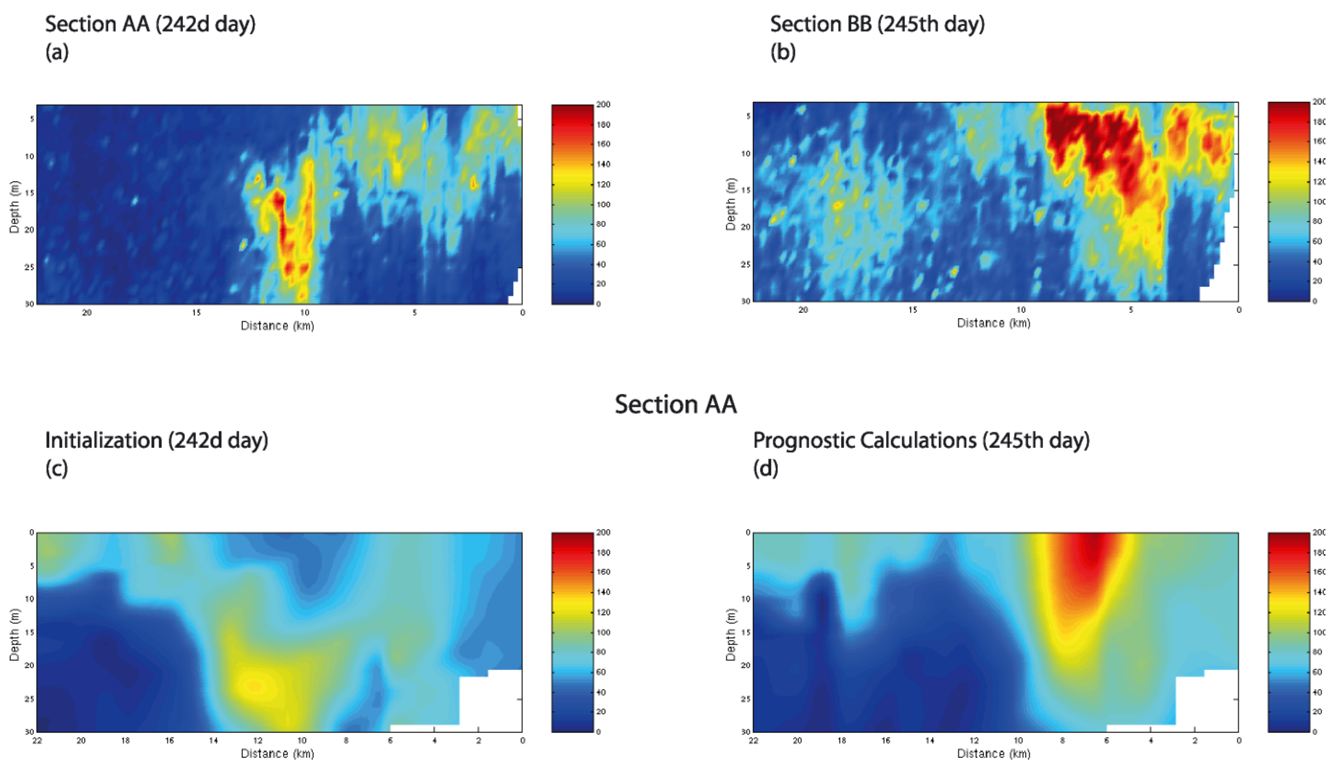

Figure 2. Observed and model-predicted BL distributions (in 109 photons /s). (a) observed BL along section AA; (b) observed BL along section BB; (c) BL distribution at the end of initialization at section AA; (d) BL distribution after three days of prognostic calculations at section AA.[Figure illustrates good agreement between observed and model-predicted locations and intensity of BL maximums].

We have been conducting tracer experiments (similar to experiments conducted for wind relaxation event during MUSE) using BL data from Steve Haddock's Spoke cruise and Mark Moline's REMUS transects during Aug. of 2002. The results are being compared to simulations conducted during the MUSE experiment. Comparisons are complicated by the fact that model predictions of physical conditions during August of 2002 are less accurate in comparisons to predictions during MUSE. During the MUSE wind relaxation event, the model was forced with the 9 km atmospheric forcing from the Navy COAMPS model, and CODAR-derived surface currents (with good spatial and temporal coverage) were assimilated into the model. However, during August of 2002, only 27 km resolution COAMPS forcing was available, and CODAR surface currents coverage had many gaps in space and time. We are planning to conduct simulations during the time frame of the AOSNII experiment (August of 2003) when 3 km resolution COAMPS forcing is available and CODAR coverage was good. Comparisons of tracer simulations during upwelling and wind relaxation events of August 2003 will allow the determination of optimal locations of BL surveys and optimize strategy of BL sampling during the major circulation regimes found in the Bay.

Following results in (Shulman et al., 2003), we conducted sensitivity studies of bioluminescence intensity with respect to variability of Monterey Bay circulation patterns and anomalies of the bioluminescence concentrations over 1- 3 days prior to the observational time. Analysis of these preliminary sensitivity studies for BL surveys taken during August 2000 (MUSE) experiment is under way.

ICON and frsICON models, initially designed for studying mesoscale features such as eddies and upwelling filaments, were designed without tidal forcing. However, the inclusion of tidal forcing is crucial for accurate BL predictions. We have now implemented tidal forcing into the ICON model. Comparison with sea level observations have led to some initial corrections. There is now good agreement between model-predicted and observed sea levels at coastal tidal stations (Fig. 3), but further analysis and testing is ongoing. Also, tuning of model tidal currents is needed as well as analysis of model internal tides predictions in the Monterey Bay.

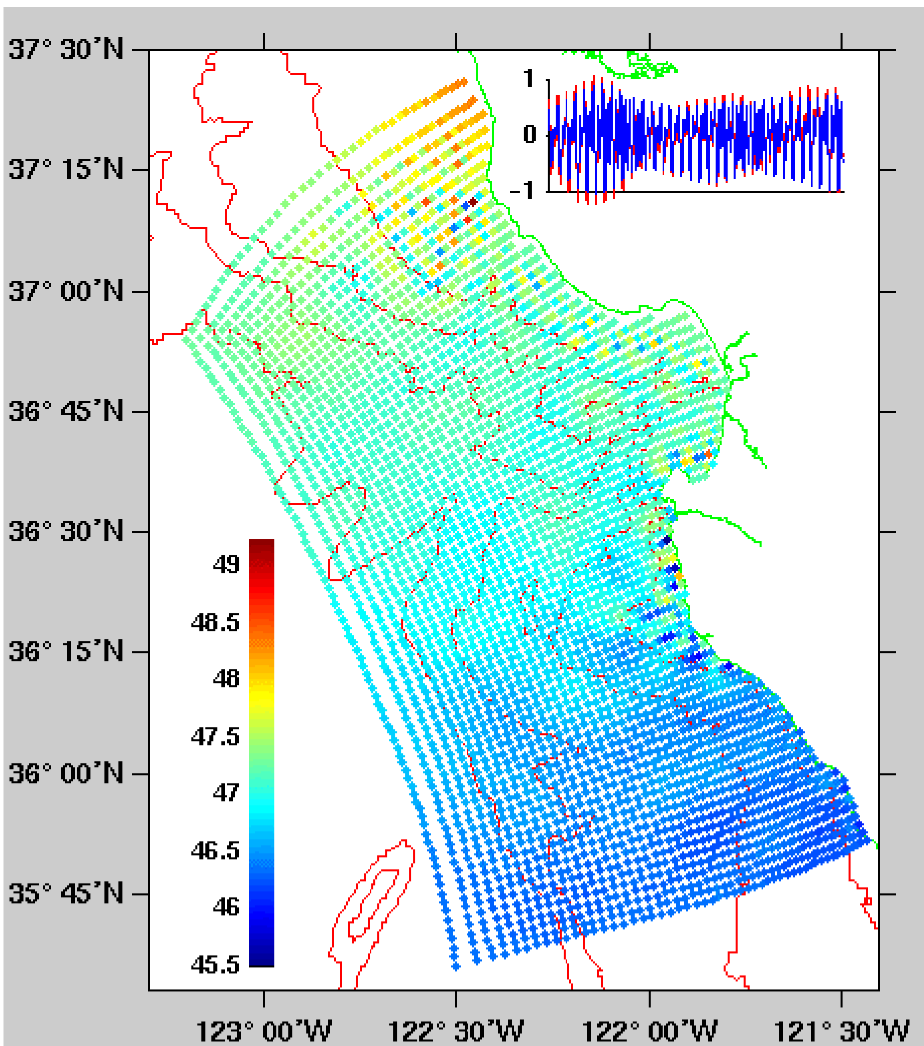

Figure 3. Amplitude of the M2 tidal constituent (color bar in cm) for the tidally forced ICON model. 34-day time series of sea level (m) at Monterey (red is measured, blue is modeled) is shown at the upper right.

IMPACT/APPLICATIONS

Prediction of the bioluminescence potential is critical for numerous naval operations, including preventing detection of covert operations involving submarines, Swimmer Delivery Vehicles and AUVs, and – conversely - in aiding detection of enemy incursions. In most cases, only limited *in situ* sampling of BL is possible immediately prior to, or during, these activities. The proposed research will provide technology and recommendations for optimizing this sampling and for use of these limited BL observations for short-term BL forecasts by tracers with the use of circulation model predictions.

TRANSITIONS

Historical ICON model outputs were provided to AOSN II community and were used for tune ups of HOPS and ROMS systems, skill assessments, and testing optimal control and adaptive sampling schemes with groups of gliders (Princeton and Caltech groups, E. Fiorelli et al., 2003).

RELATED PROJECTS

NRL, "Coupled Bio-Optical and Physical Processes (CoBiOPP)" (PI: J. Kindle)
I. Shulman is actively involved in bio-physical modeling of West Coast Ecosystem in the framework of this project. Larger scale West Coast predictions and atmospheric products are used for open-boundary and surface forcing in the Monterey Bay area models (ICON and frsICON models).

USM, "Real-time Observations of a Coastal Upwelling Event Using Innovative Technologies".
This grant supports University of Southern Mississippi (USM) Undergraduate Computer Science student providing technical and programming support of Dr. Shulman's research activities conducted in the framework of ONR's "Autonomous Ocean Sampling Network II (AOSN II)" Experiment in the Monterey Bay.

MBARI "High-Resolution Measurements of Coastal Bioluminescence; Improving Short-Term Predictability Across Seasons" (PI: S. Haddock)
Modeling activities are undertaken in conjunction with the high-resolution bioluminescence observational program being conducted by Dr. Haddock in the Monterey Bay area.

Projects funded by ONR in the framework of "Autonomous Ocean Sampling Network II (AOSN II) Experiment".
Coordination with a joint effort by the Harvard, MBARI, WHOI, NPS, Princeton, CalTech, JPL, NRL Monterey, CalPoly in designing and building an Adaptive Coupled Observation/Modeling Prediction System in the Monterey Bay. Some projects are listed below:

MBARI, "Autonomous Ocean Sampling Network II (AOSN II): System Engineering and Project Coordination" (PIs: J. G. Bellingham and P. Chandler)

Princeton and Caltech, "Underwater Glider Networks and Adaptive Ocean Sampling"
(PIs: Naomi Leonard, Clarence Rowley, and Jerrold Marsden)

Development of a Regional Coastal and Open Ocean Forecast System:
Harvard Ocean Prediction System (HOPS) (Included under this are "Quantitative Interdisciplinary Adaptive Sampling OSSEs for Monterey Bay and the California Current System -

AOSN-II" and "Adaptive Sampling OSSEs for Monterey Bay and the California Current System - AOSN-II") (PI: A. R. Robinson)

Development of a Monterey Bay Forecasting System Using The Regional Ocean Modeling System (ROMS) (PI: Yi Chao)

An Autonomous Glider Network for the Monterey Bay Predictive Skill Experiment / AOSN-II (PI: David M. Fratantoni)

NPS, "Aerial Surveys of the Atmosphere and Ocean off Central California" (PIs: S. R. Ramp, J. D. Paudan, W. Nuss, and C. A. Collins)

CalPoly, "Quantification of Littoral Bioluminescence Structure and Induced Water Leaving Radiance" (PI: M. Moline)

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PUBLICATIONS

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